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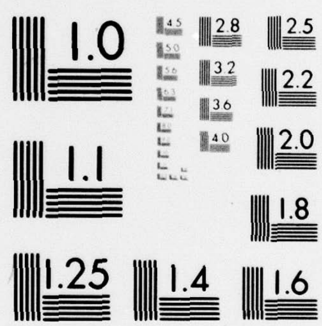
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VISUAL ACCOMMODATION RESPONSES IN A VIRTUAL IMAGE ENVIRONMENT

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The virtual images generated for helmet mounted displays and head-up displays are reflected by beam splitters to the eyes of a user. The influence of the beam splitters, with and without images reflected, on the accommodation responses of observers was measured utilizing an eyetracker which continuosly monitored the accommodation response. The results indicate that the presence of the beam splitter aids in maintaining accommodation at or near infinity.

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INTRODUCTION

Assumptions have been made about the relationship between the accommodation response of the eye and the presence of a virtual image projected at infinity in the visual field. These assumptions have not been verified, and if they are incorrect they could have serious implications for the design and use of various types of virtual image display devices. The virtual image displays include two types of displays which are used in an aircraft environment, the Head-Up Displays, (HUDs) and the Helmet Mounted Displays, (HMDs). In the HUD, images are reflected from a beam splitter, or combining glass, which is mounted on the aircraft at a nominal distance of 54 cm from the pilot's eye point. The beam splitter is fixed in the pilot's field of view, and, because of the exit pupil of the optical system, prescribes a relatively small area within which the pilot is permitted to move and continue to view the HUD images. In the HMD, the images are reflected from a beam splitter which is mounted on the crew member's helmet. In some cases, the beam splitter is a small reflector mounted inside the visor of the helmet. In other cases, the beam splitter is a small reflector permanently attached to an image generating device such as a cathode ray tube (CRT). In still other cases, the beam splitter is the helmet visor. The visor is shaped so that it is a refracting reflector and becomes a part of the optical system of the display. Developments currently in progress will apply diffractive optics techniques to the generation of HUD and HMD images.

The HMDs have been developed to provide relief from restrictions on the aircrew members imposed by the use of traditional panel mounted displays and HUDs by supplementing these devices with the helmet mounted devices. The helmet mounted devices also provide an additional dimension to the control and guidance functions performed by aircrew members.

The ease with which an optical device is used, and the fatigue generated by the use of the device are of vital concern to the developers of the devices. Design decisions are extremely significant with regard to the eventual use of the devices. In the helmet mounted versions of the virtual image displays, two conflicting motivating factors must be resolved by the developers. The first is to provide as light weight a helmet as possible so that fatigue and hazards are minimized. The second is to provide high quality images for the display, which means stabilizing the optical system of the display, thus increasing the weight of the system on the helmet. Information which can be used by display designers to make the design decisions which are required is necessary (1) and is being developed. A previous study of the effect of virtual image projection distance provided information which suggested that the accommodation response is influenced by the presence of the virtual image generating equipment, as well as by the image itself (2). A strong indication of that study was that information which could be gained by continuously monitoring the accommodation response would be useful. The study reported here investigated the changes in accommodation as a result of virtual image manipulation in a procedure which permitted continuous observation of the accommodation response.

METHODS AND MATERIALS

APPARATUS

The apparatus consisted of a three-dimensional eyetracker, a hot pen recorder, an accommodation and eye position calibrator, a background scene and search field stimulus generator and two display simulators.

The eyetracker portion of the apparatus is a Stanford Research Institute (SRI) three-dimensional eyetracker. The instrument is a combined optometer and two-dimensional eyetracker which has been developed to measure the dynamic refractive power and the direction of gaze of the eye simultaneously. The elements of the eyetracker and the composite instrument have been described in detail elsewhere (3,4,5,6) and will only be described in summary here. The eye position tracking portion of the instrument makes use of the first and fourth Purkinje images to track the rotation of the eye. The first Purkinje image (the reflection from the front surface of the cornea) and the fourth Purkinje image (the reflection from the back surface of the lens) are located in the plane of the pupil of the eye. As the eye rotates to shift the direction of gaze, the two images move relative to one another. The positions of the images are monitored by photocells and mirrors which are adjusted to maintain the position of the images on the photocells. The electrical output of the adjustment circuits provide signals which can be recorded to indicate the horizontal and vertical rotation components of the movement of the eye.

The optometer portion of the eyetracker is shown in a conceptual diagram in figure 1. A point source, S, at infinity which is viewed through apertures A and B alternately will be imaged at point C if the eye is focussed at infinity. If the eye is focussed nearer or farther (negative focus) than infinity, the images of the source through each aperture will be located at points other than C. The location of the reflected retinal images on a split field photocell (SPF) can be used as part of a feedback circuit to adjust the illuminating conditions such that the reflection of the images of the source through the apertures are steady on the SPF. The adjustment of the feedback circuit provides a direct measure of the instantaneous refractive power of the eye which can be recorded (6). The optical system of the optometer is, of course, more elegant than that shown in the conceptual diagram of figure 1, and is explained in detail in reference 6.

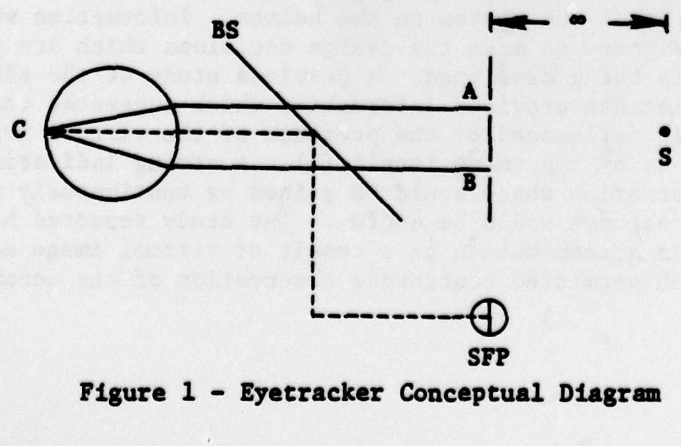


Figure 1 - Eyetracker Conceptual Diagram

The signals from the eyetracker were recorded on a Sanborn eight-channel thermal oscillographic recorder with 350-1300C DC-coupling preamplifiers. The responses and signals recorded were horizontal and vertical eye movement signals from the 1st and 4th image trackers, accommodation, slide presentation and the observer's target detection response.

The accommodation and eye position calibrator consisted of targets located at specified positions for which the eyetracker output of an observer's response could be recorded. Targets of equal visual angle and luminance were presented at 1, 2, 5 and 16 meters (nominal optical infinity), and the observer's accommodation responses as registered by the eyetracker were recorded. The eye position calibrator consisted of a target which was located at 1 meter from the eyepoint and was moved in measured steps along an arc of a 1 meter radius circle. The tracking response as registered by the eyetracker was recorded.

A projector was used to provide a small red fixation spot on a screen located 16 meters from the observer's eyepoint. The spot was used to direct the observer's gaze as required. A second projector provided a series of scenes on the screen during a trial. An aircraft target was present in each scene, and the observer searched each scene until the target was located.

A HUD and an HMD simulator were utilized to provide the virtual image conditions. The HUD was an actual aircraft instrument which was mounted on a platform which would permit the center of the combining glass of the HUD to be centered in the line of sight at 57 cm distance from the eyepoint as required. The HMD simulator consisted of a small projector and a beam splitter mounted on a head band which allowed an image to be projected to the right eye of the observer. The eyetracker monitored the left eye of the observer.

The optical adjustments of the two display simulators were measured with a calibrated telescope and determined to be adjusted so that the reflected virtual images were projected at infinity. The luminances of all calibration and experimental targets were measured with a model 1980A Pritchard Photometer which was calibrated with a Gamma Scientific 100 ftL standard source.

The observer's horizontal eye position measurements were calibrated by recording the eye position when the observer viewed targets positioned at 15, 10 and 5 degrees to the left of center, centered, and 7.5 and 5 degrees to the right of center. The vertical eye position was calibrated by recording the eye position when the observer viewed targets on the screen positioned at the center, upper and lower left, and upper and lower right of the screen corresponding to angles of 0 degrees, and 3 degrees 5 minutes above, below, left and right of center. The observer's level of accommodation was calibrated by recording the accommodation response when the observer viewed the accommodation targets which were centered at 1, 2, 5 and 16 meters distant from the eyepoint. Calibration curves were drawn so that recorder needle deflection could be converted to angle of movement in a vertical or horizontal direction and diopters of accommodation.

PROCEDURE

One half hour prior to the start of each experimental session, 2.5 percent neosynephrine ophthalmic solution was administered to each eye of the observer in order to dilate the pupils of the observer and reduce the noise in the recordings due to pupillary contractions as the stimulus conditions changed. The observer sat in a dark room for 25 minutes to speed the pupillary dilation and to control adaptation level. Preliminary trials with and without the application of neosynephrine confirmed that the amplitude of the response was not measurably reduced by the use of the mild midriatic. The noise in the recordings was significantly reduced. After the adaptation period, the experimental session was started.

The observer positioned himself on the dental impression bite board and fixated the small red fixation point which was projected onto the screen. The initial adjustments of the recorder were made. When all adjustments were completed, an accommodation calibration check run was conducted in which a sequence of 10 stimuli, alternately at the 1 and 16-meter distance were presented to the observer for 15 seconds each. The stimuli required no horizontal or vertical eye movements. The eye responses were recorded during the calibration run. The observer was then permitted to relax for 1.5 minutes. Following the rest interval, the fixation point was turned on again and the observer again positioned himself in the apparatus. When he was properly positioned, a sequence of 10 slides was presented, each slide being viewed for 15 seconds. Each slide, a photograph of either a land, sea or air scene, contained the silhouette of an aircraft which subtended a visual angle of either 9 or 11 minutes in its longest aspect. The observer was required to search the slide until the aircraft silhouette was located, press his hand switch to signal that the aircraft had been located and return his gaze to the center of the screen. After 10 slides had been presented, the observer was allowed to relax for 1.5 minutes. At the end of the rest period, the observer was signalled to reposition himself on the bite board and the slide search procedure was repeated. A total of 20 slide search sequences was conducted, after which the appropriate beam splitter was positioned. The beam splitter was then removed and the final sequence of the experimental session, a calibration check run, was conducted. During each sequence, recordings of the horizontal and vertical components of the first and fourth Purkinje image positions, the accommodation response, the slide presentations and the observer's detection response were made. The order of presentation of the slides was randomized in each experimental session, and the order was different from session to session. The experimental design is shown in table I.

TABLE I - Experimental Design

Search Target (min.)	No Beam Splitter	HUD	HMD
9	A	B	C
11	D	E	F

RESULTS

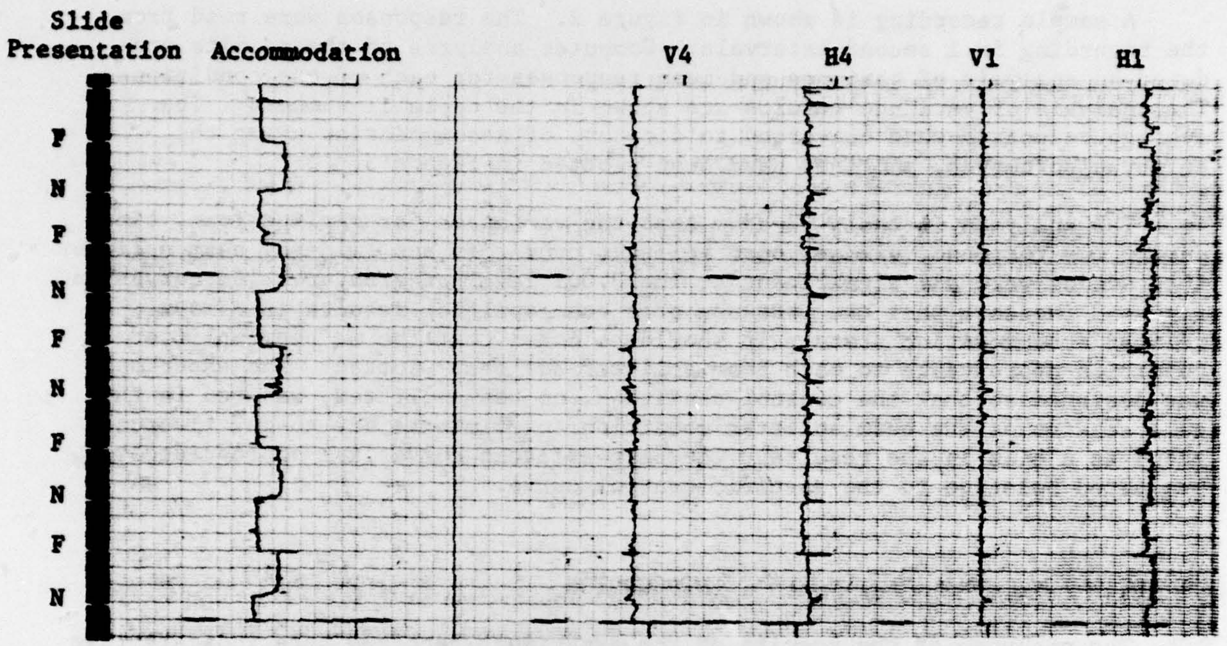
A sample recording is shown in figure 2. The responses were read from the recording in 1 second intervals. Computer analyses of the results produced an analysis of variance and mean responses for each of the conditions. The analysis of variance results are shown in the table II summary. The average responses were converted to diopters of accommodation using the calibration curves, and they have been plotted in figure 3.

The analyses in table II show that the variances for replications, time during the response, slides, beam splitter condition and slide by beam splitter interaction were all significant at the 0.001 level or greater. The curves in figure 3 indicate that the presence of a beam splitter results in a more relaxed accommodation state. It should be noted that the no beam splitter condition appropriate to each beam splitter has been plotted. The experiment was designed so that the control condition, no beam splitter, was run in the same session as the beam splitter condition to eliminate day-to-day fluctuations as a bias in the results. The beam splitter curves are appropriately evaluated relative to the specific control curve.

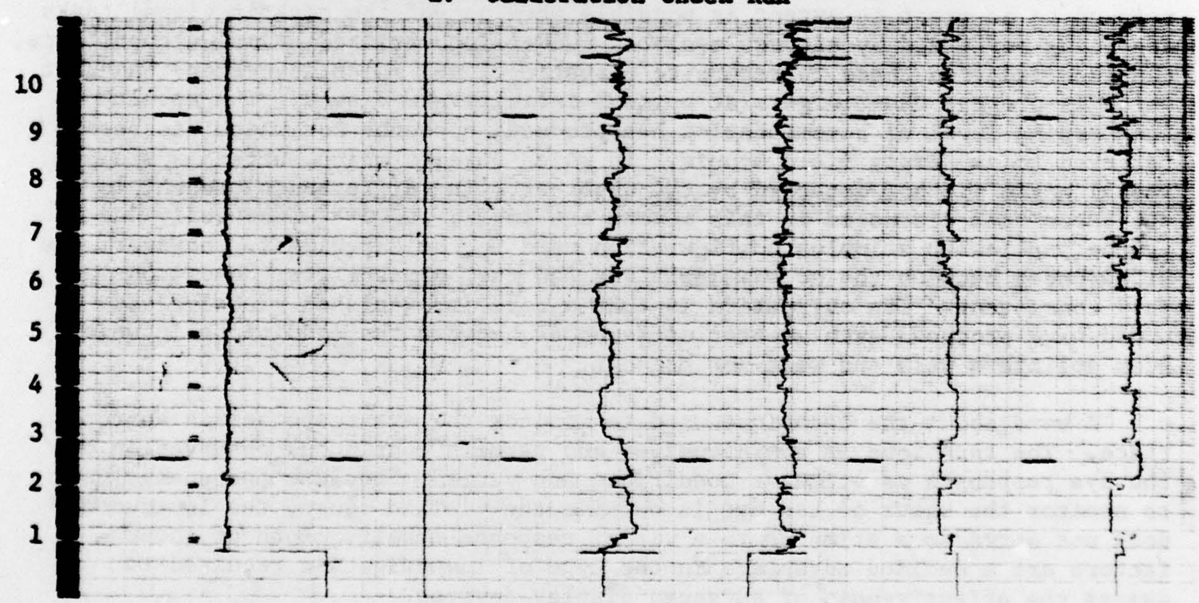
DISCUSSION

The analyses of the results of the experiment reported here indicate that the use of a beam splitter may provide a positive influence in addition to the information conveying function. It is important that the accommodation be relaxed to as great an extent as possible when out-of-the cockpit visual tasks are being performed by aircrew members. Under impoverished stimulus conditions, the accommodation tends to return to a resting level which is nearer than that which is present when targets at optical infinity are viewed. The result of the resting level of accommodation has produced a phenomenon which has been referred to as "empty field myopia," in which objects which subtend a small visual angle are not detected by the observer. The differences present in the experiment discussed in this report are small, and are undoubtedly due to the particular stimulus configuration used in the experiment. However, the differences between the no beam splitter and the beam splitter conditions are very consistent. The suggestion is that a more impoverished visual field would have produced even greater differences between the conditions in which beam splitters were and were not present.

A word about the technique used to monitor the eye responses is appropriate. The technique is nonintrusive, and permits continuous observation of the eye responses as stimulus conditions are varied. Because the energy used to monitor the state of the eye is outside the visible range, the instrument does not serve as a stimulus to a visual response itself. Both of these factors are a decided advantage in the type of investigation required to assess the effectiveness of advanced display devices.



a. Calibration Check Run



b. Slide Search Sequence

Figure 2 - Sample Recording

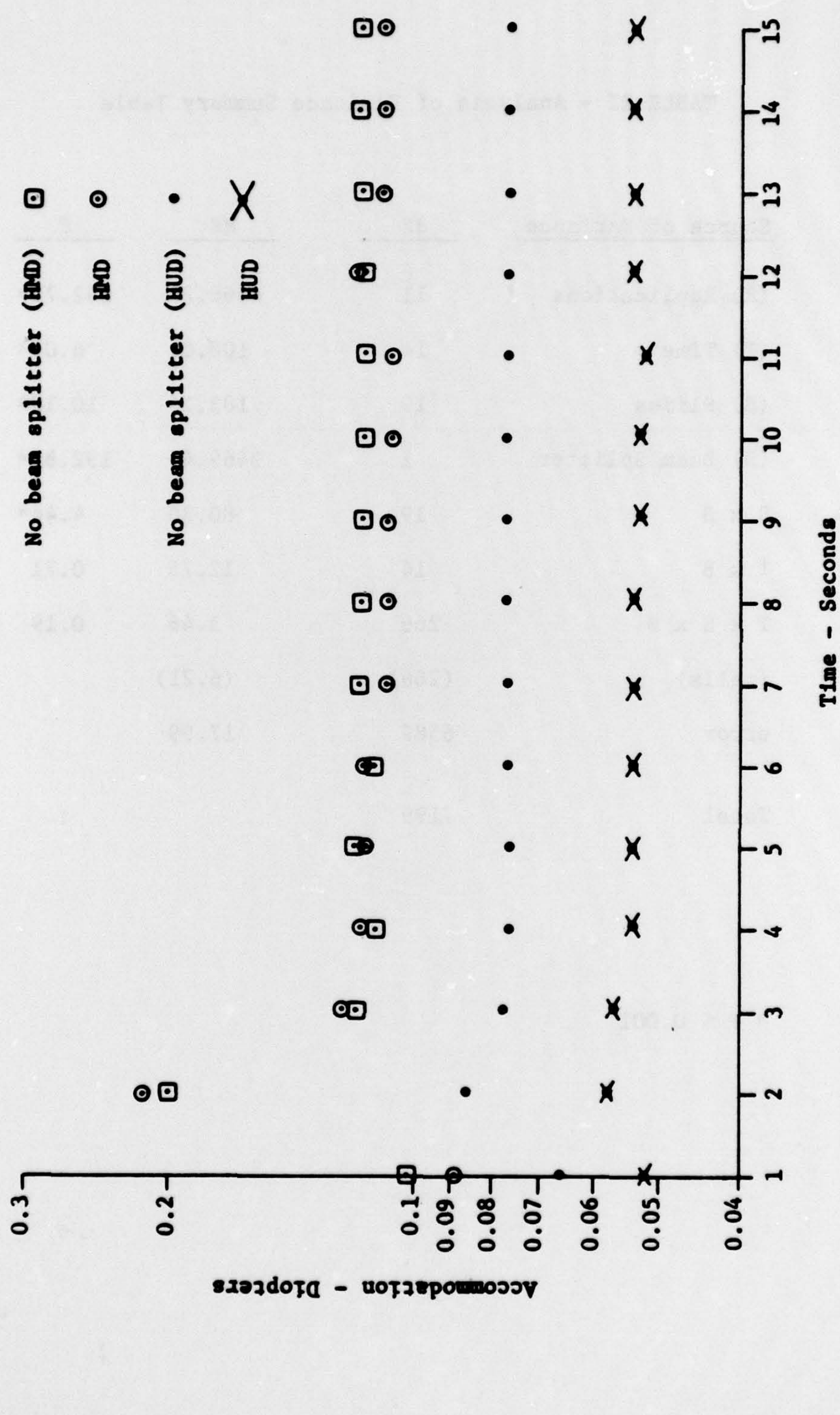


Figure 3 - Average Responses in Diopters of Accommodation

TABLE II - Analysis of Variance Summary Table

Source of Variance	df	MS	F
(R) Replications	11	4366.20	242.70*
(T) Time	14	108.01	6.00*
(S) Slides	19	183.14	10.18*
(B) Beam Splitter	1	3469.45	192.85*
S x B	19	80.30	4.46*
T x B	14	12.75	0.71
T x S x B	266	3.46	0.19
(cells)	(266)	(6.21)	
error	6589	17.99	
Total	7199		

* $P < 0.001$

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